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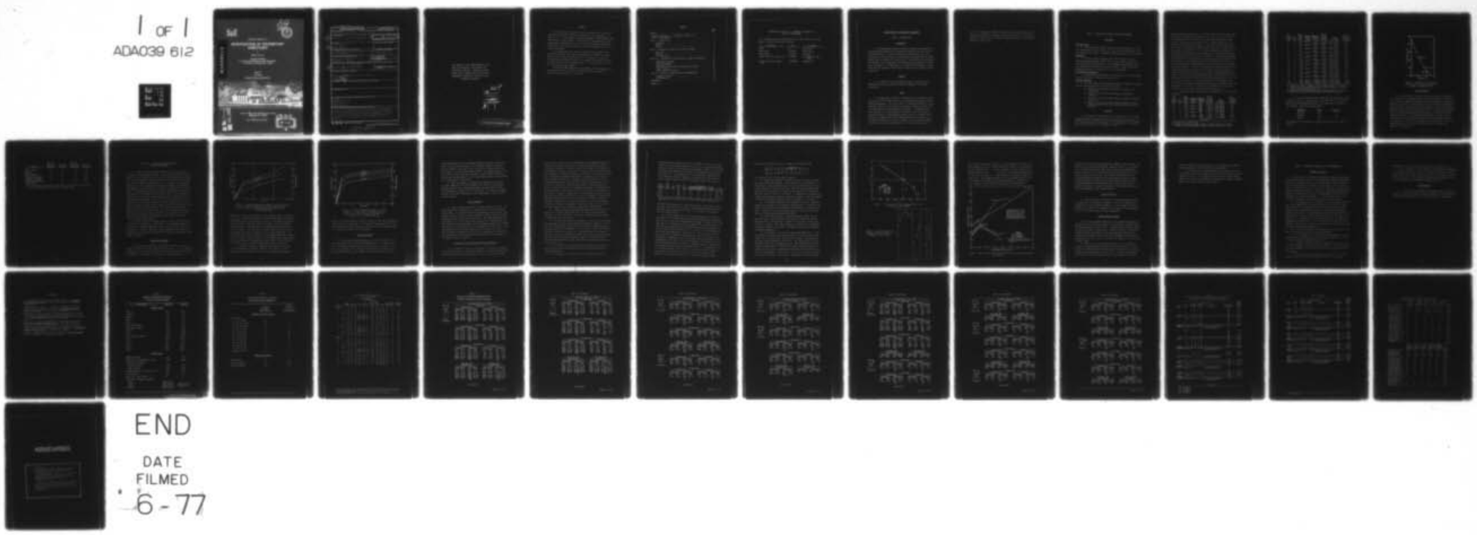

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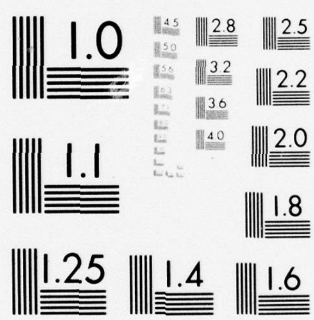

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TECHNICAL REPORT C-77-1

INVESTIGATION OF PROPRIETARY ADMIXTURES

by

William O. Tynes

Concrete Laboratory
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April 1977

Final Report

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Three special water-reducing admixtures for concrete were evaluated according to test method CRD-C 87-72. Tests were made to determine the effects of these admixtures on the properties of concrete. Air-entrained concrete mixtures were made with and without these admixtures. All three of the admixtures permitted water reductions exceeding 15 percent. The admixtures met all the requirements of CRD-C 87-72 except for frost resistance.

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PREFACE

The investigation reported herein was authorized by a first indorsement dated 8 May 1974 from the Office, Chief of Engineers, U. S. Army, to a U. S. Army Engineer Waterways Experiment Station (WES) letter dated 29 April 1974, subject: Project Plan for Investigation of Testing Methods and Apparatus, Tests of Proprietary Admixtures (CWR Work Unit 31138). The Technical Monitor for this investigation was Mr. J. H. Rhodes, DAEN-CWE-C.

The investigation was conducted between 1974 and 1976 at the Concrete Laboratory, WES, under the supervision of Messrs. B. Mather, Chief of the Concrete Laboratory, and J. M. Scanlon, Jr., Chief of the Engineering Mechanics Division. The members of the staff actively concerned with the work included Messrs. W. O. Tynes and W. B. Lee. Mr. Tynes prepared this report.

Directors of WES during this investigation and the preparation of this report were COL G. H. Hilt, CE, and COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
cubic yards	0.7645549	cubic metres
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic yard	0.59327631	kilograms per cubic metre
pounds (force) per square inch	0.006894757	megapascals

INVESTIGATION OF PROPRIETARY ADMIXTURES

PART I: INTRODUCTION

Background

1. New proprietary products intended to modify the properties of portland-cement concrete are developed and marketed from year to year. Some modifications of concrete properties resulting from the use of these products can be reduction in the amount of mixing water for equal workability, acceleration or retardation of setting time, more efficient entrainment of air, improvement in workability, and reduction in bleeding. Therefore, it is appropriate to evaluate the properties of these materials that appear to have potential value for use in Corps of Engineers work.

Purpose

2. The purpose of this investigation was to evaluate certain admixtures for use in concrete in Corps of Engineers Civil Works construction.

Scope

3. Two admixtures (SM-21-74 and SM-28-74) were evaluated according to CRD-C 87-72[1] (ASTM C 494-71) for acceptability as type A, water-reducing admixtures. One round (batch) of concrete was made on a third admixture (SM-4-75), which was also evaluated according to CRD-C 87-72 for compliance with the requirements for type A. Preliminary tests were conducted on a fourth admixture (SM-13-74), but testing was not completed because no significantly greater effect was produced when it was used as compared with water-reducing admixtures in general use. Two additional batches of concrete (mixture B1) were made with admixture SM-21-74, and one additional batch of concrete was made with

each of the admixtures, SM-28-74 (mixture C1) and SM-4-75 (mixture E1), reducing the quantity of admixture from that used in the initial test. Mixtures B2 and C2 were also made with admixture SM-21-74 and admixture SM-28-74, respectively.

PART II: MATERIALS, MIXTURES, AND TEST SPECIMENS

Materials

Portland cement

4. Type II portland cement (RC-658) from Texas and type II portland cement (RC-705) from Alabama were used in this investigation. Table 1 presents the results of chemical and physical tests of the cements.

Aggregates

5. The fine natural aggregate (WES S-4(51)) and the coarse crushed limestone aggregate (CRD G-31(14)) were obtained from Mississippi and Tennessee, respectively. The aggregates were graded to meet the requirements of CRD-C 87-72[1] (ASTM C 494-71). Table 2 gives the gradings and results of physical tests of the aggregates.

Air-entraining admixture

6. The air-entraining admixture (AEA-937) used in this investigation was a solution of neutralized vinsol resin.

Chemical admixture

7. The four commercially available proprietary admixtures obtained for this investigation were described as follows:

- a. SM-21-74 is a condensation product of melamine and formaldehyde.
- b. SM-28-74 is a sulfonated naphthalene formaldehyde condensate.
- c. SM-4-75 is a high molecular weight sulfonated naphthalene condensate.
- d. SM-13-74 is a high molecular weight naphthalene formaldehyde condensate and a high molecular weight aliphatic phosphate.

Mixtures

8. Air-entrained concrete mixtures, containing 1-in. (25.4-mm)* nominal maximum size aggregate, were proportioned with and without the

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

chemical admixtures under test. The cement content of all mixtures was 517 lb/yd^3 (307 kg/m^3); slump was 2-1/2 ± 1/2 in. (63.5 ± 12.7 mm) for all mixtures except B2; and the air content when determined by ASTM Method C 231-75 was 6.0 ± 1 percent for all mixtures except B2. The difference between the air content of the control concrete and that of the concrete containing the admixture under test did not exceed 0.5 percent except for mixture B2. All concrete mixtures except mixture B2 were proportioned, batched, mixed, sampled, and cured according to the requirements of CRD-C 87-72 with one exception. A reference laboratory Type II cement was used rather than a blend as specified in CRD-C 87-72. The quantity of air-entraining admixture varied with the different cements and proprietary admixtures and also as the amounts of the admixtures used changed. For some of the admixtures a greater amount of air-entraining admixture was required than used in the control mixture to obtain the desired air content, and for others a smaller amount was required. Table 3 gives the chemical admixture and the quantities of air-entraining admixture for each of the mixtures, designated A, B, B1, B2, C, C1, C2, D, E, and E1. The batches were mixed in accordance with CRD-C 87-72, and the water-reducing admixture was introduced as the last ingredient to the batch. Following such introduction, the specified 2-min mixing, 3-min rest, and 1-min remixing were done.

9. Pertinent data on each mixture are summarized in the following tabulation:

Mixture Designation	Batch No.	Water-Cement Ratio by Wt	Chemical Admixture		Maximum Size Aggregate in. (mm)	Slump in. (mm)	Air Content, %, Pressure Method*
			Designation	Quantity Used			
A	1	0.45	--	None	1 (25.4)	2-3/4 (69.8)	5.8
B	1	0.34	SM-21-74	3%**	1 (25.4)	2-1/2 (63.5)	6.2
A	2	0.45	--	None	1 (25.4)	2-3/4 (69.8)	6.0
B	2	0.34	SM-21-74	3%**	1 (25.4)	2-1/2 (63.5)	5.8
A	3	0.45	--	None	1 (25.4)	2-3/4 (69.8)	6.0
B	3	0.34	SM-21-74	3%**	1 (25.4)	2-1/2 (63.5)	5.7
A	1	0.45	--	None	1 (25.4)	2-1/2 (63.5)	6.3
C	1	0.37	SM-28-74	1.49%†	1 (25.4)	2 (50.8)	6.3
A	2	0.45	--	None	1 (25.4)	2-3/4 (69.8)	5.8

(Continued)

* Method CRD-C 41 (ASTM C 231).
** Percent of solution by weight of cement (solution contains 0.20 solids).
† Percent of solution by weight of cement (solution contains 0.42 solids).

Mixture Designation	Batch No.	Water-Cement Ratio by Wt	Chemical Admixture Designation	Chemical Admixture Quantity Used	Maximum Size Aggregate in. (mm)	Slump in. (mm)	Air Content, %, Pressure Method
C	2	0.37	SM-28-74	1.49%†	1 (25.4)	2-1/2 (63.5)	6.0
A	3	0.45	--	None	1 (25.4)	2-1/4 (57.2)	5.7
C	3	0.37	SM-28-74	1.49%†	1 (25.4)	2 (50.8)	5.8
A	1	0.45	--	None	1 (25.4)	2-1/2 (63.5)	6.0
D	1	0.41	SM-13-74	0.9%††	1 (25.4)	2-1/2 (63.5)	6.2
A	1	0.45	--	None	1 (25.4)	2 (50.8)	5.7
E	1	0.35	SM-4-75	1.49%‡	1 (25.4)	2-1/2 (63.5)	5.7
A	1	0.45	--	None	1 (25.4)	2-1/4 (57.2)	5.7
C1	1	0.38	SM-28-74	1.2%†	1 (25.4)	2-1/4 (57.2)	5.8
A	1	0.45	--	None	1 (25.4)	2-1/4 (57.2)	6.1
B1	1	0.39	SM-21-74	1.25%**	1 (25.4)	2-1/2 (63.5)	6.6
A	2	0.45	--	None	1 (25.4)	2-3/4 (69.8)	6.3
B1	2	0.39	SM-21-74	1.25%**	1 (25.4)	2-1/4 (57.2)	6.6
A	1	0.45	--	None	1 (25.4)	2-3/4 (69.8)	6.2
E1	1	0.39	SM-4-74	0.47%‡	1 (25.4)	2-1/4 (57.2)	6.5
A	1	0.45	--	None	1 (25.4)	2-3/4 (69.8)	6.2
C2	1	0.39	SM-28-74	0.42%†	1 (25.4)	2-1/2 (63.5)	6.5
A	1	0.45	--	None	1 (25.4)	2-3/4 (69.8)	6.3
B2	1	0.39	SM-21-74	1.55%**	1 (25.4)	4-1/4 (108.0)	10.0
A	1	0.45	--	None	1 (25.4)	2-3/4 (69.8)	6.3
B2	2	0.39	SM-21-74	1.55%**	1 (25.4)	4-1/4 (108.0)	10.0
B2	2	0.39	SM-21-74	1.55%**	1 (25.4)	2-1/4 (57.2)‡‡	5.2‡‡

** Percent of solution by weight of cement (solution contains 0.20 solids).
† Percent of solution by weight of cement (solution contains 0.42 solids).
†† Percent solids by weight of cement.
‡ Percent of solution by weight of cement (solution contains 0.34 solids).
‡‡ Slump and air content after reducing the air content by vibration.

10. The liquid water-reducing admixtures were batched by weight. However, in order to compute dosage in the same units as were used to batch the air-entraining admixture, it was necessary to compute the unit weights. The values obtained were:

Admixture	ml/lb	Solids, %
SM-21-74	405	20
SM-28-74	370	42
SM-4-75	380	34

The relation of unit weight to reported solids content is shown in Figure 1.

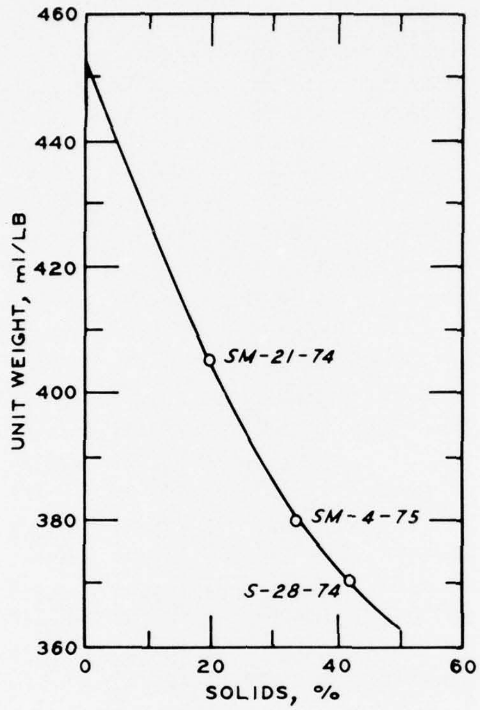


Figure 1. Relation of solids content (as reported by producer) to unit weight of liquid admixtures

Test Specimens

11. Three batches of concrete were made for each test condition, i.e., three for the reference mixture A and three each for mixtures B and C containing chemical admixtures SM-21-74 and SM-28-74, respectively. One batch of concrete of each was made on three different casting days. Only one batch of concrete was made for mixtures D and E that contained admixtures SM-13-74 and SM-4-75, respectively. No freezing-and-thawing tests or length-change measurements were made on concrete containing admixture SM-13-74. The tests and minimum number of types of tests conducted of the freshly mixed concrete and of the hardened concrete for each batch of the other two admixtures are shown below. Also, the same number and type of tests were made on all of the additional batches of concrete cast.

Types	No. of Types of Specimens	No. of Test Ages	No. of Conditions of Concrete	No. of Specimens
Water content	--	1	2	*
Slump	1	1	2	*
Air content	1	1	2	*
Time of setting	1	*	2	6
Compressive strength	1	5	2	30
Flexural strength	1	3	2	18
Freezing and thawing	1	1	2	12
Length change	1	1	2	6

* One test determined on each batch of concrete mixed.

PART III: DISCUSSION OF TEST RESULTS OF CHEMICAL ADMIXTURES

12. Table 3 shows the concrete mixture data and the results of the tests on freshly mixed concrete. Tables 4 and 5 present the individual test and average results of tests on hardened concrete specimens. As a result of reported differences between test results in this study and those of commercial laboratories, i.e., resistance to freezing and thawing on two of the admixtures, additional mixtures using three of the admixtures, one per mixture, were made to investigate this discrepancy. It was suggested that the quantity of admixture being used may have caused the low durability factor (DFE) value or the slump was not high enough. All mixtures except mixture B2 were proportioned in accordance with requirements of CRD-C 87-72. The slump and air contents of mixture B2 were varied somewhat to provide information as to the effect of higher slump and using a higher initial air content and slump. The air content was reduced from 10 to 5.2 percent; the slump was lowered from 4-1/4 in. (108.0 mm) to 2-1/4 in. (57.2 mm) on one batch, and the other batch was used as produced. This reduction in air con tent was accomplished by vibrating the complete batch of concrete 2 min with an internal vibrator.

13. Table 6 gives the average results for each of all the types of tests with requirements of CRD-C 87-72. The following analysis of the results of chemical admixtures used in mixtures B and C will show the effects of chemical admixtures on both compressive and flexural strength, water reduction, frost resistance, time of setting, and length change on drying.

Compressive Strength

14. The average compressive strengths of concrete, as shown in Figure 2 and Table 4, contain different admixtures at 3, 7, 28, 180, and 365 days age. The average strength result (control mixture A), plotted in Figure 2 for each age, is the average of the specimens from

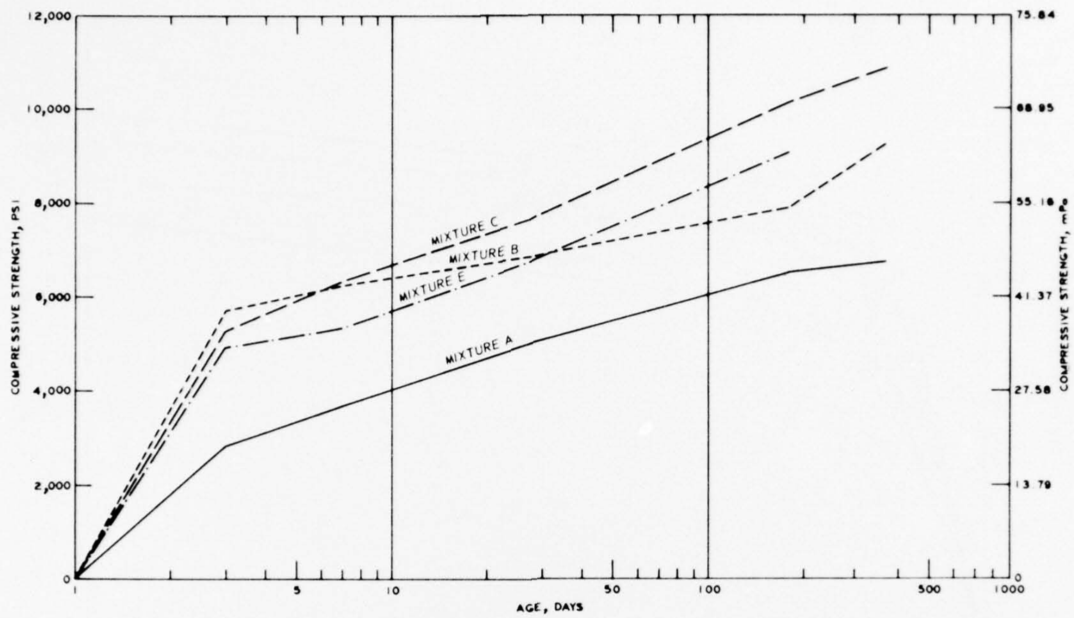


Figure 2. Average compressive strength of control mixture A (i.e., average of specimens from batches 1-8) and mixtures B, C, and E containing chemical admixtures at 3, 7, and 28 days age

batches 1-8 of the control mixture. The strength results of mixtures B, C, and E containing admixtures are considerably higher at each age tested than those of the reference mixture A. The average compressive strength results of mixture C were the highest of all the mixtures tested except at 3 days age where the strength results of mixture B were the highest. The compressive strength results of mixture B were also higher than those of mixture E at 3, 7, and 28 days age. The strength gain of concrete with two of the chemical admixtures (mixtures C and E) is quite similar (Figure 3). The compressive strength results met the specification requirements of CRD-C 87-72 at each age tested for all five types of chemical admixtures as given in CRD-C 87.

15. When the quantity of admixture was decreased for each of the three admixtures (SM-21-74, SM-28-74, and SM-4-75) from that used initially in mixtures B, C, and E, the compressive strength of

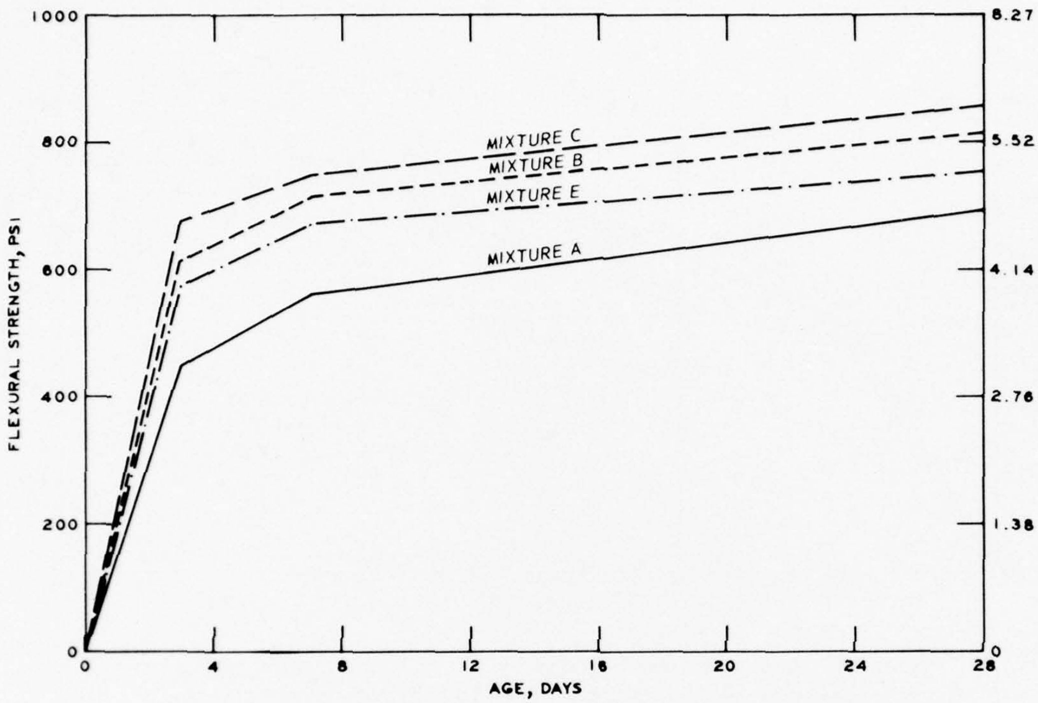


Figure 3. Average flexural strength of control mixture A (i.e., average of specimens 1-8) and mixtures B, C, and E containing chemical admixtures at 3, 7, and 28 days age

mixture B1 containing admixture SM-21-74 failed to meet the requirements of CRD-C 87-72 at 28 days age. The compressive strength results of the other admixtures met the requirements of CRD-C 87-72 at each age tested, i.e., through 28 days age for one admixture.

Flexural Strength

16. The average flexural strength of concrete, as shown in Figure 3 and Table 4, contain different admixtures at 3, 7, and 28 days age. The average strength result (control mixture A), plotted in Figure 3 for each age, is the average of the specimens from batches 1-8 of the control mixture. The strength results of mixtures B, C, and E

containing admixtures are considerably higher at each age tested than those of the reference mixture A. The strength results of mixture C were the highest at all ages tested, and those of mixture B were the next highest of the three admixtures tested. The strength gain of concrete with the three chemical admixtures is quite similar (Figure 3). The flexural strength results of all three admixtures met the specification requirements of CRD-C 87-72.

17. When the quantity of admixture was decreased for each of the three admixtures (SM-21-74, SM-28-74, and SM-4-75), the flexural strength of mixture B1 containing admixture SM-21-74 failed to meet the requirements of CRD-C 87-72 at 28 days age. The flexural strength results of the other admixtures met the requirements of CRD-C 87-72 at all ages tested.

Water Reduction

18. Table 5 gives the results of the water-reduction tests. The water reductions for mixtures B, C, and E were 25, 18, and 22 percent, respectively. It has been reported by Aignesberger, Fah, and Rey[2] that a water reduction of 20 percent was obtained in mortar using a chemical admixture similar to that used in mixture B. All three admixtures used in mixtures B, C, and E, respectively, resulted in a higher degree of water reduction than customarily used water-reducing admixtures; however, the amount of water reduction met the requirements of CRD-C 87-72. When the quantities of these three admixtures were lowered, the amount of water reduction decreased but still met the requirements of CRD-C 87-72. The least amount of water reduction obtained with the lower quantities of admixture was 12.6 percent.

Resistance to Accelerated Freezing and Thawing

19. The results of tests for resistance to freezing and thawing show that resistance to freezing and thawing of concrete containing the water-reducing admixtures (mixtures B, C, and E) was lower than that

of the control mixture A not containing any of the admixtures (Table 5). Mixture B's relative resistance to freezing and thawing was reduced to 25 percent of mixture A (control) batches 1-3; mixture C was reduced to approximately 54 percent of mixture A (control) batches 4-6; and mixture E was reduced to 17 percent of mixture A (batch 8). All tests for resistance to freezing and thawing made when the specimens were 14 days old were according to CRD-C 20.[1] Specimens from all mixtures B, C, and E containing chemical admixtures failed to meet the requirements of CRD-C 87-72 for resistance to freezing and thawing. Specimens from one batch of concrete (mixture B1) containing 1.25 percent of admixture (SM-21-74) by weight of cement had a DFE of 77 which met the requirements of CRD-C 87-72. However, a repeat batch of this mixture resulted in an average DFE value of 40 which did not meet the requirements of CRD-C 87-72. Specimens from one batch of concrete (mixture C1) with 1.2 percent of admixture (SM-28-74) and from one batch (mixture C2) with 0.42 percent of admixture (SM-28-74) by weight of cement had a DFE of 26 and 56, respectively, which did not meet the requirements of CRD-C 87-72.

20. Another high-gain water-reducing admixture was received for testing for compliance with CRD-C 87-72 for type A and gave similar results, i.e., the resistance to freezing and thawing was insufficient to comply with the specification.

21. In connection with the performance of tests on it, one special batch was made in which the air-entraining admixture quantity in the control batch (178 ml/yd^3) was also used in the batch to which the water-reducing admixture was introduced. The result was a batch with 7-1/2-in. (190.5-mm) slump and 13 percent air. Specimens molded from it gave a DFE of 35. The batch which had the proper air content and slump and was made with the water-reducing admixture under test contained 73 ml of air-entraining admixture per cubic yard, and the specimens molded from it had a DFE of 13.

22. The behavior of these admixtures is different from that reported by all previous workers who have studied conventional water-reducing admixtures.

23. Micrometric air content and air void spacing factor ($\bar{L}$)

determinations were made by CRD-C 42-71[1] (ASTM C 457-71) on one beam from each of the concrete mixtures (A, B, B1, C, C1, and E) after they had been tested for frost resistance according to CRD-C 20. For frost resistance, the spacing factor should not be greater than 0.008 in. (0.203 mm).[3-5] The spacing factors of the specimens containing the three admixtures SM-21-74, SM-28-74, and SM-4-75 are shown below as equal or higher than the 0.008-in. (0.203-mm) value. The values of

Water-Reducing Admixture	Mixture Designation	Batch No.	Specimen No.	DFE 300 Cycles	Air Content, %: Micrometric Method: Entrained	Entrapped	Total	Pressure Method*	$\bar{L}$ in.	$\bar{L}$ mm
None	A	1	9357	84	5.5	0.6	6.1	6.3	0.003	0.08
SM-21-74	B	1	9290	32	2.4	1.2	3.6	6.2	0.011	0.28
SM-28-74	C	2	9358	55	3.8	1.1	4.9	6.0	0.008	0.20
SM-4-75	E	1	9476	14	2.7	1.0	3.7	5.7	0.012	0.30

* Based on freshly mixed concrete (CRD-C 41[1]); other air data based on hardened concrete (CRD-C 42[1]).

specimens from mixtures B, C, and E are 0.011 in. (0.279 mm), 0.008 in. (0.203 mm), and 0.012 in. (0.305 mm), respectively, and thus are considerably higher than the value 0.003 in. (0.08 mm) of the specimen from the control mixture.

24. The air content data of the freshly mixed concrete tests, using CRD-C 41,[1] in which the concrete was consolidated by rodding show that the air contents were approximately the same. However, the air content data of the hardened concrete, using CRD-C 42,[1] in which the concrete was also consolidated by rodding show considerable difference in the air content between mixtures A, B, C, and E. For the hardened concrete containing admixtures, (mixtures B, C, and E), the air content data indicate a considerable decrease in the total air content. Also, the amount of entrapped air of the specimens containing admixtures is approximately twice that of the control specimen. Micrometric air content determinations were also made on a companion beam not subjected to freezing-and-thawing tests from mixtures B1 and C1. From mixture C1, $\bar{L}$ of the beam was higher than 0.008 in. (0.203 mm), and from mixture B1 it was lower than 0.008 in. (0.023 mm). This lower spacing factor agrees with the higher DFE value of 77 obtained on companion beams.

The data for $\overline{L}$ and DFE of these two beams are presented below:

Water-Reducing Admixture	Mixture Designation	Batch No.	Specimen No.	DFE 300 Cycles	Air Content, %				$\overline{L}$	
					Micrometric Method			Pressure Method*		
					Entrained	Entrapped	Total		in.	mm
SM-28-74	C1	1	9482	26	2.8	0.3	3.1	5.8	0.009	0.229
SM-21-74	B1	1	9488	77	5.8	0.8	6.6	6.6	0.004	0.102

* Based on freshly mixed concrete (CRD-C 41[1]); other air data based on hardened concrete (CRD-C 42[1]).

The relation of $\overline{L}$ to DFE is shown in Figure 4.

25. Twenty-five batches of concrete were used to mold test specimens for freezing and thawing: 12 from mixture A, 7 from mixture B, 5 from mixture C, and 2 from mixture E. All of the DFE values for the B, C, and E mixtures (Figure 4) were lower than the lowest specimen from any batch of control mixture A except for one batch of B1 that gave a DFE of 77 and $\overline{L}$ of 0.004 in. (0.102 mm). No explanation is available as to why this batch had a good air void system. Figure 5 shows the ranges in DFE of two specimens from each batch of mixtures A, B, C, and E.

26. The mixture proportions were adjusted to give the specified slump and air content of the completely mixed concrete. Therefore, the mixture just before the water-reducer was added was of very dry consistency. However, the full 2/3/1 mixing cycle was given to the mixture after the water-reducing admixture was added.

27. Davis[6] reported that a chemical admixture similar to that used in mixture B did not affect the properties of hardened concrete. He stated that: "The admixture is added to the concrete on-site just before it is placed. The normal dosage is 1.5 percent of the admixture by weight of cement....The effect is temporary 30-60 minutes depending on ambient temperatures."

28. Two batches of concrete were made using mixture B2. In the first batch of concrete, the slump was 4-1/4 in. (108 mm) and the air content of the freshly mixed concrete was 10 percent. Specimens were made and tested according to CRD-C 87-72. The average DFE of the two specimens containing the admixture was 52. The average DFE of the two control specimens was 81. Even with the higher slump and higher air content of the concrete containing the admixture the results failed to meet the requirements of CRD-C 87-72, i.e., the DFE value was not equal to at least 80 percent of the control. Apparently, the higher slump

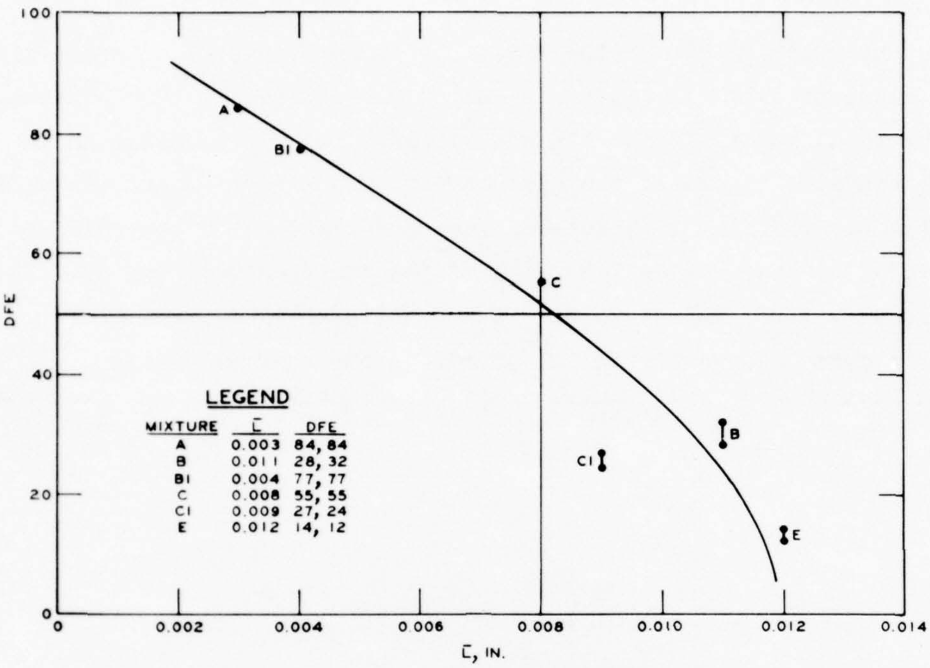
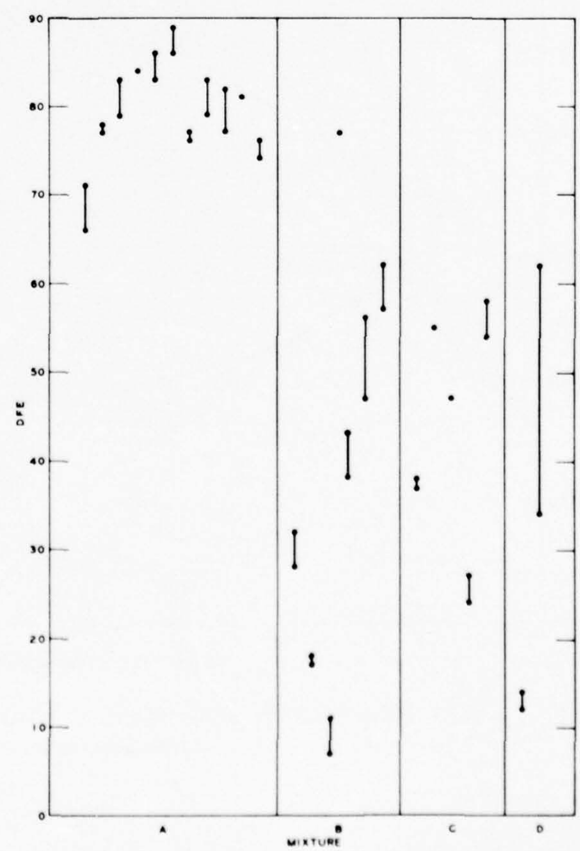


Figure 4. Relation of air void spacing factor (I) to durability factor (DFE)

Figure 5. Range in DFE of two specimens from each batch of mixtures A, B, C, and E



did not have any effect on the DFE. The second batch of concrete also had a slump of 4-1/4 in. (108 mm) and an air content of 10.0 percent, but the total batch of concrete was vibrated for 2 min, using an internal vibrator to reduce the air content to 5.2 percent and the slump to 2-1/4 in. (57.2 mm). Specimens were made and tested according to CRD-C 87-72. The average DFE value of the two specimens was 60. The test results still failed to meet the requirements of CRD-C 87-72.

29. Figure 6 shows the effect of adding the water-reducing

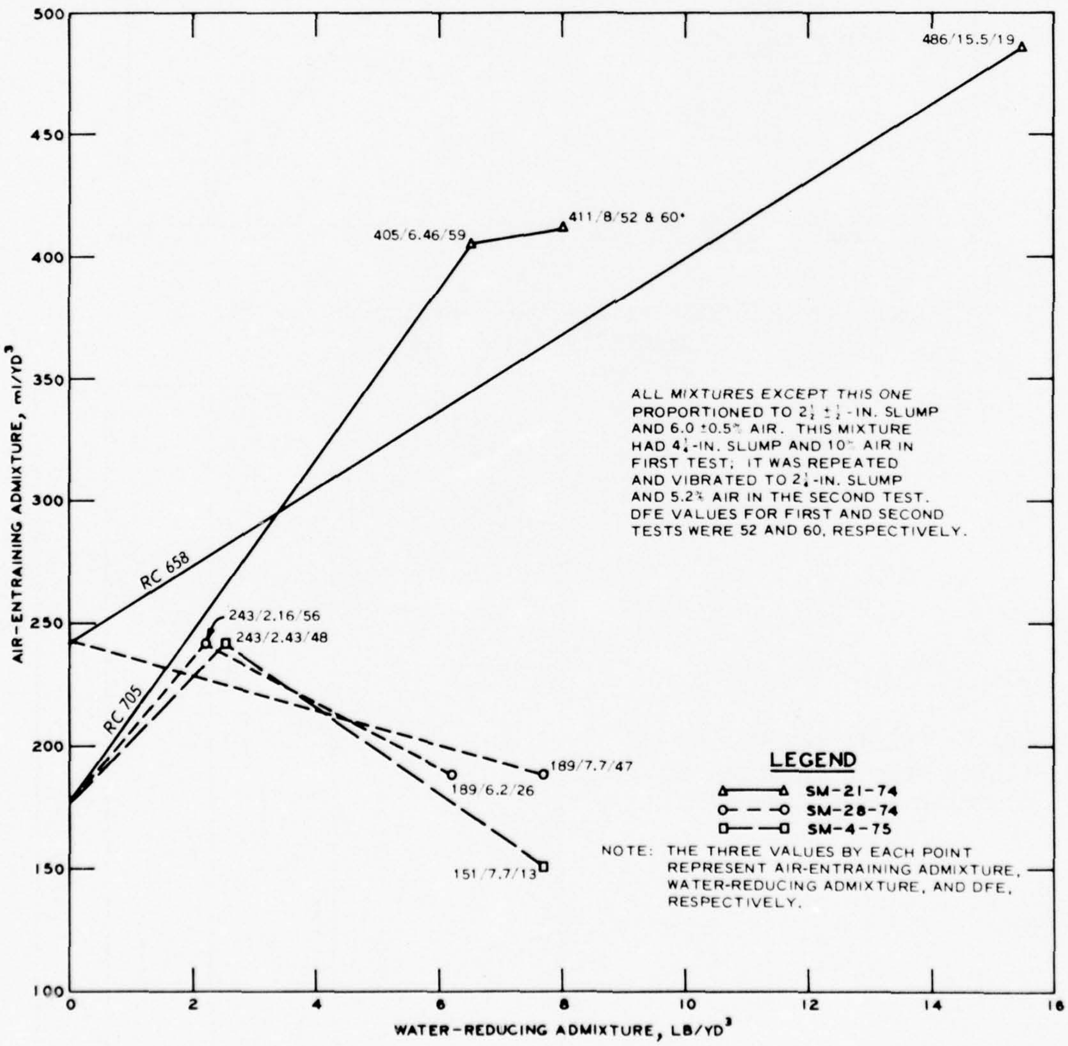


Figure 6. Effect of water-reducing admixtures on air-entraining admixture demand

admixtures on the air-entraining admixture demand of the concrete. The quantity of air-entraining admixture required to give 6 $\pm$ 0.5 percent air in concrete made with RC 658 portland cement was significantly greater than with RC 705 portland cement, possibly due in part to the higher surface area of RC 658. When SM-21-74 was added, the air-entraining admixture demand increased substantially; when the other liquid admixtures were added in the larger amounts tested, the air-entraining admixture demand decreased but increased when smaller amounts were added. It would be desirable to know whether other air-entraining admixtures show the same behavior.

Time of Setting

30. Table 5 presents the results of the time-of-setting tests. The quantities used allowed the admixture to meet the time-of-set requirements for type A chemical admixture. If the dosage had been increased, it is possible the admixtures would have met the requirement for one of the other types of chemical admixtures.

Length Change on Drying

31. The length-change deviation of the specimens containing an admixture from the control specimens was very small for mixtures meeting the requirements of CRD-C 87-72. Specimens tested were well within the specified limits of CRD-C 87-72, as shown in Table 5. The length change on drying for mixture B2 containing admixture SM-21-74 and 10 percent air content failed to meet the requirement of CRD-C 87-72. Apparently, this was a result of the high air content of 10 percent and a higher slump.

32. Tables 4 and 5 also show the results of the one batch of concrete containing chemical admixture SM-13-74 (mixture D). At the dosage of the admixture that was used, the concrete failed to meet the time-of-setting requirement of CRD-C 87-72. A smaller dosage should have been used if this requirement were to have been met, but since

the water reduction was approaching that of customarily used water-reducing admixture, further testing was discontinued.

33. In Table 6, the average values only of each type test for each mixture and specified limits of CRD-C 87-72 are given for ease of comparison of data. In columns where there is more than one batch number, the values are an average of that number of batches, otherwise values of one batch represent the one value.

PART IV: SUMMARY OF RESULTS AND THE RECOMMENDATION

Summary of Results

34. Resistance to freezing and thawing was significantly reduced by the addition of all three of the water-reducing chemical admixtures tested. An average DFE value of 76 was obtained on control batches 1-3, 85 on control batches 4-6, and 76 on control batch 8 of control mixture A. Average DFE's of 19, 47, and 13 were obtained on specimens with admixtures SM-21-74, SM-28-74, and SM-4-75, respectively; these values caused the admixtures not to meet the requirements of CRD-C 87-72 for resistance to freezing and thawing. It is clear that this was due to a failure to produce a proper air void system in the concrete.

35. The admixtures are not marketed as air-entraining admixtures. These data suggest that in the event they are to be used in concrete that needs to be air entrained in order to be frost resistant, they should be used together with an effective air-entraining admixture, perhaps with the use of an air-detraining agent as an intermediate step. When the high increase in water reduction was used in this study, i.e., nominal 13 to 25 percent, the concrete failed to meet the durability requirements of CRD-C 87-72. This does not mean to infer that the admixture in question will or will not comply with the specification when evaluated at lower water reductions.

36. The water reductions for admixtures SM-21-74, SM-28-74, and SM-4-75 were 25, 18, and 22.2 percent, respectively.

37. The specimens of the concrete containing admixtures had less length change on drying than those of the control mixture with the air content and slump as required by CRD-C 87-72.

38. Admixtures SM-21-74, SM-28-74, and SM-4-75 met the time-of-setting requirements for type A chemical admixture. The admixtures met all the requirements of CRD-C 87-72 except for resistance to freezing and thawing.

39. When these chemical admixtures are used to obtain a high degree of water reduction, they may be expected not to meet the

requirements for frost resistance in CRD-C 87-72 (ASTM C 494-71).

40. As a result of this investigation, Headquarters of Department of Army (HQDA), DAEN-CWE-C, plans to distribute an Engineer Technical Letter (ETL) to all Corps of Engineer Divisions and Districts, cautioning them in the use of these special water-reducing admixtures in concrete to be exposed to freezing-and-thawing conditions.

Recommendation

41. In order to take advantage of the high increase in water reduction of these special water-reducing admixtures in concrete exposed to freezing and thawing while wet, further research is recommended.

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5. Kleiger, P., "Effect of Entrained Air on Strength and Durability of Concrete Made with Various Maximum Sizes of Aggregate," Proceedings, Highway Research Board, Vol 31, 1952, pp 177-201.

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Table 1

Chemical and Physical Properties of Type II Portland Cement

Properties	RC-658	RC-705
Chemical Data		
SiO_2, %	22.4	22.8
Al_2O_3, %	4.9	4.0
Fe_2O_3, %	3.9	4.2
MgO, %	1.0	3.5
SO_3, %	2.0	1.7
Loss on ignition, %	0.8	0.6
Insoluble residue, %	0.12	0.26
Na_2O, %	0.45	0.12
K_2O, %	0.14	0.49
Total alkalies, Na_2O, %	0.54	0.44
C_3S, %	50.5	45.6
C_3A, %	6.4	3.5
C_2S, %	26.0	30.9
CaO, %	65.0	62.8
C_4AF, %	11.8	12.7
Physical Data		
Specific gravity	3.15	3.15
Fineness, air permeability, cm^2/g	3295	3150
Time of set, Gilmore:		
Initial, hr:min	3:20	3:15
Final, hr:min	5:45	5:45
Mortar expansion, autoclave test, %	0.00	0.10
Air content, %	8.1	8.4
False set - Pen. F/Init., %	87	--
Compressive strength, psi (MPa)		
1 day	1010 (6.96)	--
3 days	2180 (15.03)	1630 (11.24)
7 days	3160 (21.79)	2280 (15.72)
28 days	4800 (33.09)	--

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Table 2

Gradings and Physical Properties of Fine and Coarse Aggregates

	Coarse Aggregate CRD G-31(14)	Fine Aggregate (Sand) WES-1 S-4(51)
Gradings, Percent Passing		
Sieve Size:		
1 in. (25.0 mm)	100	--
3/4 in. (19.0) mm)	75	--
1/2 in. (12.5 mm)	50	--
3/8 in. (9.5 mm)	25	--
No. 4 (4.75 mm)	--	100
No. 8 (2.36 mm)	--	88
No. 16 (1.18 mm)	--	73
No. 30 (600 μm)	--	47
No. 50 (300 μm)	--	16
No. 100 (150 μm)	--	3
No. 200 (75 μm)	--	--
Passing No. 200	--	--
Physical Properties		
Absorption, %	0.4	0.2
Specific gravity	2.72	2.64
Fineness modulus	7.00	2.73

Table 3

Mixture Data and Results of Tests of Freshly Mixed Concrete

(Individual Values and Averages)

Mixture Designation	Batch No.	Maximum Size Aggregate in.	Maximum Size Aggregate mm	Cement Content lb/yd^3	Cement Content kg/m^3	Chemical Admixture Designation	Chemical Admixture Amount Used Weight of Cement %	Chemical Admixture Amount Used Weight of Cement lb/yd^3	Chemical Admixture Amount Used Ratio, Pounds Water to Air-Entrained Admixture ml/yd^3	Water-Cement Ratio by Weight	Slump in.	Slump mm	Air Content, %, Pressure Method	Sand-Aggregate Ratio, % by Volume	Quantity Air-Entraining Admixture ml/yd^3
Cement RC-658															
A	1	1	25.4	517	307	--	--	--	0.96	0.45	2-3/4	69.8	5.8	39	243
A	2	1	25.4	517	307	--	--	--	0.96	0.45	2-3/4	69.8	6.0	39	243
A	3	1	25.4	517	307	--	--	--	0.96	0.45	2-3/4	69.8	6.0	39	243
	Average	1	25.4	517	307	--	--	--	0.96	0.45	2-3/4	69.8	5.9	39	243
B	1	1	25.4	5.7	307	SM-21-74	3.00*	15.51	0.33	0.34	2-1/2	63.5	6.2	39	486
B	2	1	25.4	517	307	SM-21-74	3.00*	15.51	0.33	0.34	2-1/2	63.5	5.8	39	486
B	3	1	25.4	517	307	SM-21-74	3.00*	15.51	0.33	0.34	2-1/2	63.5	5.7	39	486
	Average	1	25.4	517	307	SM-21-74	3.00*	15.51	0.33	0.34	2-1/2	63.5	5.9	39	486
A	4	1	25.4	517	307	--	--	--	0.96	0.45	2-1/2	63.5	6.3	39	243
A	5	1	25.4	517	307	--	--	--	0.96	0.45	2-3/4	69.8	5.8	39	243
A	6	1	25.4	517	307	--	--	--	0.96	0.45	2-1/4	57.2	5.7	39	243
	Average	1	25.4	517	307	--	--	--	0.96	0.45	2-1/2	63.5	5.9	39	243
C	1	1	25.4	517	307	SM-28-74	1.49**	7.70	0.97	0.37	2	50.8	6.3	39	189
C	2	1	25.4	517	307	SM-28-74	1.49**	7.70	0.97	0.37	2-1/2	63.5	6.0	39	189
C	3	1	25.4	517	307	SM-28-74	1.49**	7.70	0.97	0.37	2	50.8	5.8	39	189
	Average	1	25.4	517	307	SM-28-74	1.49**	7.70	0.97	0.37	2-1/4	57.2	6.0	39	189
A	7	1	25.4	517	307	--	--	--	0.96	0.45	2-3/4	69.8	6.0	39	243
D	1	1	25.4	517	307	SM-13-74	0.90†	4.65	0.47	0.41	2-1/2	63.5	6.2	39	459
Cement RC-705															
A	8	1	25.4	517	307	--	--	--	1.31	0.45	2	50.8	5.7	39	178
E	1	1	25.4	517	307	SM-4-75	1.49††	7.70	1.15	0.35	2-1/2	63.5	5.7	39	151
A	9	1	25.4	517	307	--	--	--	1.31	0.45	2-1/4	57.2	5.7	39	178
C1	1	1	25.4	517	307	SM-28-74	1.20**	6.20	1.00	0.38	2-1/4	57.2	5.8	39	189
A	10	1	25.4	517	307	--	--	--	1.31	0.45	2-1/4	57.2	6.1	39	178
A	11	1	25.4	517	307	--	--	--	1.31	0.45	2-3/4	69.8	6.3	39	178
	Average	1	25.4	517	307	--	--	--	1.31	0.45	2-1/2	63.5	6.2	39	178
B1	1	1	25.4	517	307	SM-21-74	1.25*	6.46	0.49	0.39	2-1/2	63.5	6.6	39	405
B1	2	1	25.4	517	307	SM-21-74	1.25*	6.46	0.49	0.39	2-1/4	57.2	6.6	39	405
	Average	1	25.4	517	307	SM-21-74	1.25*	6.46	0.49	0.39	2-1/4	57.2	6.6	39	405
A	12	1	25.4	517	307	--	--	--	1.31	0.45	2-3/4	69.8	6.2	39	178
E1	1	1	25.4	517	307	SM-4-75	0.47††	2.43	0.83	0.39	2-1/4	57.2	6.5	39	243
A	12	1	25.4	517	307	--	--	--	1.31	0.45	2-3/4	69.8	6.2	39	178
C2	1	1	25.4	517	307	SM-28-74	0.42**	2.17	0.83	0.39	2-1/2	63.5	6.5	39	243
A	13	1	25.4	517	307	--	--	--	1.31	0.45	2-3/4	69.8	6.3	39	178
B2	1	1	25.4	517	307	SM-21-74	1.55*	8.01	0.47	0.39	4-1/4	108.0	10.0	39	411
A	13	1	25.4	517	307	--	--	--	1.31	0.45	2-3/4	69.8	6.3	39	178
B2‡	1	1	25.4	517	307	SM-21-74	1.55*	8.01	0.47	0.39	4-1/4 2-1/4	108.0 57.2	10.0 5.2	39	411

* Percent of solution by weight of cement. Solution contains 0.20 solids (3% = 6278 ml/yd^3) (1.25% = 2616 ml/yd^3) (1.55% = 3240 ml/yd^3).
** Percent of solution by weight of cement. Solution contains 0.42 solids (1.49% = 2849 ml/yd^3) (1.2% = 2294 ml/yd^3) (0.42% = 799 ml/yd^3).
† Percent solids by weight of cement.
†† Percent of solution by weight of cement. Solution contains 0.34 solids (1.49% = 2926 ml/yd^3) (0.47% = 923 ml/yd^3).
‡ Slump and air content were reduced from 4-1/4 to 2-1/4 in. (114.3 to 57.2 mm) and 10.0 to 5.2 percent, respectively, by internal vibration.

Table 4

Results of Individual Compressive and Flexural Strength Tests and Averages

Strength Tests, psi (MPa)

3 Days Age

Mixture A B Batch No.	Compressive Mixture A psi	Compressive Mixture A MPa	Compressive Mixture B psi	Compressive Mixture B MPa	Flexural Mixture A psi	Flexural Mixture A MPa	Flexural Mixture B psi	Flexural Mixture B MPa
1 1	2860	19.72	5540	38.20	465	3.21	685	4.72
2 2	2900	19.99	6410	44.20	450	3.10	600	4.14
3 3	2880	19.86	5190	35.78	455	3.14	565	3.90
Average	2880	19.86	5710	39.37	455	3.14	615	4.24
% Control			198				135	

7 Days Age

Compressive Mixture A psi	Compressive Mixture A MPa	Compressive Mixture B psi	Compressive Mixture B MPa	Flexural Mixture A psi	Flexural Mixture A MPa	Flexural Mixture B psi	Flexural Mixture B MPa
3710	25.58	6320	43.57	560	3.86	785	5.41
3510	24.20	6840	47.16	690	4.76	750	5.17
3500	24.13	5500	37.02	545	3.76	615	4.24
3570	24.61	6220	42.88	600	4.14	715	4.93
		174				119	

28 Days Age

Compressive Mixture A psi	Compressive Mixture A MPa	Compressive Mixture B psi	Compressive Mixture B MPa	Flexural Mixture A psi	Flexural Mixture A MPa	Flexural Mixture B psi	Flexural Mixture B MPa
5040	34.75	7040	48.54	600	4.14	890	6.14
5110	35.23	7680	52.95	680	4.69	870	6.00
4860	33.51	5860	40.40	750	5.17	685	4.72
5000	34.47	6860	47.30	675	4.65	815	5.62
		137				121	

180 Days Age Compressive Mixture A psi	MPa	Mixture B psi	MPa	365 Days Age Compressive Mixture A psi	MPa	Mixture B psi	MPa
6650	45.85	7880	54.33	6680	46.06	10,710	73.84
6130	42.26	8980	61.91	6290	43.37	9,430	65.02
6460	44.54	6890	47.50	6610	45.57	7,500	51.71
6410	44.20	7920	54.61	6530	45.02	9,210	63.50
		124				141	

(Continued)

Table 4 (Continued)

Mixture A	Mixture C	Strength Tests, psi (MPa)							
		3 Days Age							
		Compressive				Flexural			
Batch No.		Mixture A		Mixture C		Mixture A		Mixture C	
A	C	psi	MPa	psi	MPa	psi	MPa	psi	MPa
4	1	2640	18.20	5430	37.44	440	3.03	715	5.43
5	2	2700	18.62	5170	35.65	425	2.93	625	4.31
6	3	2880	19.86	5250	36.20	480	3.31	695	4.79
Average		2740	18.89	5280	36.40	450	3.10	680	4.69
% Control				193				151	

7 Days Age							
Compressive				Flexural			
Mixture A		Mixture C		Mixture A		Mixture C	
psi	MPa	psi	MPa	psi	MPa	psi	MPa
3500	24.13	6540	45.09	510	3.52	750	5.17
3800	26.20	6260	43.16	540	3.72	755	5.20
3890	26.82	6250	43.09	580	4.00	--	--
3730	25.72	6350	43.78	545	3.76	750	5.17
		170				138	

28 Days Age							
Compressive				Flexural			
Mixture A		Mixture C		Mixture A		Mixture C	
psi	MPa	psi	MPa	psi	MPa	psi	MPa
4550	31.37	8020	55.30	650	4.48	820	5.65
5180	35.71	7950	54.81	700	4.83	845	5.83
5090	35.09	6960	47.99	785	5.41	900	6.21
4940	34.06	7640	52.68	710	4.90	855	5.90
		155				120	

180 Days Age				365 Days Age			
Compressive				Compressive			
Mixture A		Mixture C		Mixture A		Mixture C	
psi	MPa	psi	MPa	psi	MPa	psi	MPa
6390	44.06	10,460	72.12	6620	45.64	10,700	73.77
6290	43.37	9,710	66.95	6860	47.30	10,160	70.05
6900	47.57	10,250	70.67	7550	52.06	11,390	78.53
6530	45.02	10,140	69.91	7010	48.33	10,750	74.12
		155				153	

(Continued)

Table 4 (Continued)

Strength Tests, psi (MPa)

Mixture A D Batch No.	3 Days Age: Compressive, Mixture A, psi	MPa	Mixture D, psi	MPa	Flexural, Mixture A, psi	MPa	Mixture D, psi	MPa
7 1	2880	19.86	3490	24.06	450	3.10	580	4.00
% Control			121				129	

	7 Days Age: Compressive, Mixture A, psi	MPa	Mixture D, psi	MPa	Flexural, Mixture A, psi	MPa	Mixture D, psi	MPa
	3500	24.13	4160	28.68	570	3.93	640	4.41
			119				112	

	28 Days Age: Compressive, Mixture A, psi	MPa	Mixture D, psi	MPa	Flexural, Mixture A, psi	MPa	Mixture D, psi	MPa
	4860	33.51	5340	36.82	750	5.17	715	4.93
			110				95	

	180 Days Age: Compressive, Mixture A, psi	MPa	Mixture D, psi	MPa	365 Days Age: Compressive, Mixture A, psi	MPa	Mixture D, psi	MPa
	6460	44.54	6610	45.57	6610	45.57	6430	44.33
			102				97	

Mixture A E Batch No.	3 Days Age: Compressive, Mixture A, psi	MPa	Mixture E, psi	MPa	Flexural, Mixture A, psi	MPa	Mixture E, psi	MPa
8 1	2820	19.45	4910	33.85	455	3.14	575	3.96
% Control			174				126	

	7 Days Age: Compressive, Mixture A, psi	MPa	Mixture E, psi	MPa	Flexural, Mixture A, psi	MPa	Mixture E, psi	MPa
	3750	25.86	5330	36.75	530	3.65	675	4.65
			142				127	

(Continued)

Table 4 (Continued)

Mixture A E Batch No.	Strength Tests, psi (MPa) — 28 Days Age — Compressive — Mixture A psi	MPa	Mixture E psi	MPa	Flexural — Mixture A psi	MPa	Mixture E psi	MPa
8 1	5120	35.30	6790	46.82	635	4.38	755	5.21
% Control			132				118	

	180 Days Age — Compressive — Mixture A psi	MPa	Mixture E psi	MPa	365 Days Age — Compressive — Mixture A psi	MPa	Mixture E psi	MPa
8 1	7220	49.78	9040	62.33				
% Control			125					

Mixture A C1 Batch No.	3 Days Age — Compressive — Mixture A psi	MPa	Mixture C1 psi	MPa	Flexural — Mixture A psi	MPa	Mixture C1 psi	MPa
9 1	2350	16.20	4040	27.85	410	2.83	585	4.03
% Control			172				143	

	7 Days Age — Compressive — Mixture A psi	MPa	Mixture C1 psi	MPa	Flexural — Mixture A psi	MPa	Mixture C1 psi	MPa
9 1	3240	22.34	4680	32.27	505	3.48	750	5.17
% Control			144				149	

	28 Days Age — Compressive — Mixture A psi	MPa	Mixture C1 psi	MPa	Flexural — Mixture A psi	MPa	Mixture C1 psi	MPa
9 1	5180	35.71	7000	48.26	700	4.83	825	5.69
% Control			135				118	

	180 Days Age — Compressive — Mixture A psi	MPa	Mixture C1 psi	MPa	365 Days Age — Compressive — Mixture A psi	MPa	Mixture C1 psi	MPa
9 1	6220	42.89	8860	61.09				
% Control			136					

(Continued)

Table 4 (Continued)

Mixture A	Mixture B1	Strength Tests, psi (MPa) — 3 Days Age: Compressive, Mixture A psi	MPa	Compressive, Mixture B1 psi	MPa	Flexural, Mixture A psi	MPa	Flexural, Mixture B1 psi	MPa
10	1	2280	15.72	3020	20.82	405	2.79	450	3.10
11	2	2210	15.24	3160	21.79	390	2.69	505	3.48
Average		2240	15.48	3090	21.30	395	2.74	480	3.29
% Control				138				122	

Column heads for the tables below: Mixture A and Mixture B1 (or E1) are Batch Nos.

7 Days Age		Compressive, Mixture A psi	MPa	Compressive, Mixture B1 psi	MPa	Flexural, Mixture A psi	MPa	Flexural, Mixture B1 psi	MPa
		3140	21.65	3880	26.75	495	3.41	635	4.38
		2960	20.41	4180	28.82	490	3.38	545	3.76
		3050	21.03	4030	27.78	490	3.40	590	4.07
				132				120	

28 Days Age		Compressive, Mixture A psi	MPa	Compressive, Mixture B1 psi	MPa	Flexural, Mixture A psi	MPa	Flexural, Mixture B1 psi	MPa
		4870	33.58	5180	35.71	760	5.24	740	5.10
		4750	32.75	5340	36.82	760	5.24	660	4.55
		4810	33.16	5260	36.26	760	5.24	700	4.82
				109				95	

		180 Days Age, Compressive, Mixture A psi	MPa	180 Days Age, Compressive, Mixture B1 psi	MPa	365 Days Age, Compressive, Mixture A psi	MPa	365 Days Age, Compressive, Mixture B1 psi	MPa

Mixture A	Mixture E1	3 Days Age: Compressive, Mixture A psi	MPa	Compressive, Mixture E1 psi	MPa	Flexural, Mixture A psi	MPa	Flexural, Mixture E1 psi	MPa
12	1	2070	14.27	2790	19.24	370	2.55	450	3.10
% Control				135				122	

7 Days Age		Compressive, Mixture A psi	MPa	Compressive, Mixture E1 psi	MPa	Flexural, Mixture A psi	MPa	Flexural, Mixture E1 psi	MPa
		2620	18.06	3500	24.13	475	3.28	580	4.00
				134				122	

(Continued)

Table 4 (Continued)

Mixture A E1 Batch No.	Strength Tests, psi (MPa)							
	28 Days Age							
	Compressive				Flexural			
	Mixture A		Mixture E1		Mixture A		Mixture E1	
	psi	MPa	psi	MPa	psi	MPa	psi	MPa
12 1	4250	29.30	5140	35.44	660	4.55	750	5.17
% Control			121				114	
	180 Days Age				365 Days Age			
	Compressive				Compressive			
	Mixture A		Mixture E1		Mixture A		Mixture E1	
	psi	MPa	psi	MPa	psi	MPa	psi	MPa
Mixture A C2 Batch No.	3 Days Age							
	Compressive				Flexural			
	Mixture A		Mixture C2		Mixture A		Mixture C2	
	psi	MPa	psi	MPa	psi	MPa	psi	MPa
12 1	2070	14.27	3230	22.27	370	2.55	480	3.31
% Control			156				130	
	7 Days Age							
	Compressive				Flexural			
	Mixture A		Mixture C2		Mixture A		Mixture C2	
	psi	MPa	psi	MPa	psi	MPa	psi	MPa
	2620	18.06	3830	26.41	475	3.28	615	4.24
			146				129	
	28 Days Age							
	Compressive				Flexural			
	Mixture A		Mixture C2		Mixture A		Mixture C2	
	psi	MPa	psi	MPa	psi	MPa	psi	MPa
	4250	29.30	5680	39.16	660	4.55	740	5.10
			134				112	
	180 Days Age				365 Days Age			
	Compressive				Compressive			
	Mixture A		Mixture C2		Mixture A		Mixture C2	
	psi	MPa	psi	MPa	psi	MPa	psi	MPa
Mixture A B2 Batch No.	3 Days Age							
	Compressive				Flexural			
	Mixture A		Mixture B2		Mixture A		Mixture B2	
	psi	MPa	psi	MPa	psi	MPa	psi	MPa
13 1	2210	15.24	3160	21.79	390	2.69	505	3.48
% Control			143				129	

(Continued)

Table 4 (Concluded)

Strength Tests, psi (MPa)

7 Days Age

Mixture A B2 Batch No.	Compressive Mixture A psi	Compressive Mixture A MPa	Compressive Mixture B2 psi	Compressive Mixture B2 MPa	Flexural Mixture A psi	Flexural Mixture A MPa	Flexural Mixture B2 psi	Flexural Mixture B2 MPa
13 1	2960	20.41	4180	28.82	490	3.38	545	3.76
% Control			141				111	

28 Days Age

Mixture A B2 Batch No.	Compressive Mixture A psi	Compressive Mixture A MPa	Compressive Mixture B2 psi	Compressive Mixture B2 MPa	Flexural Mixture A psi	Flexural Mixture A MPa	Flexural Mixture B2 psi	Flexural Mixture B2 MPa
	4750	32.75	5340	36.82	760	5.24	660	4.55
			112				87	

Mixture A B2 Batch No.	180 Days Age Compressive Mixture A psi	MPa	Mixture B2 psi	MPa	365 Days Age Compressive Mixture A psi	MPa	Mixture B2 psi	MPa

3 Days Age

Mixture A B2(2) Batch No.	Compressive Mixture A psi	Compressive Mixture A MPa	Compressive Mixture B2(2) psi	Compressive Mixture B2(2) MPa	Flexural Mixture A psi	Flexural Mixture A MPa	Flexural Mixture B2(2) psi	Flexural Mixture B2(2) MPa
13 1	2210	15.24	4170	28.75	390	2.69	565	3.90
% Control			189				145	

7 Days Age

Mixture A B2(2) Batch No.	Compressive Mixture A psi	Compressive Mixture A MPa	Compressive Mixture B2(2) psi	Compressive Mixture B2(2) MPa	Flexural Mixture A psi	Flexural Mixture A MPa	Flexural Mixture B2(2) psi	Flexural Mixture B2(2) MPa
	2960	20.41	4520	31.16	490	3.38	705	4.86
			153				144	

28 Days Age

Mixture A B2(2) Batch No.	Compressive Mixture A psi	Compressive Mixture A MPa	Compressive Mixture B2(2) psi	Compressive Mixture B2(2) MPa	Flexural Mixture A psi	Flexural Mixture A MPa	Flexural Mixture B2(2) psi	Flexural Mixture B2(2) MPa
	4750	32.75	4820	33.23	760	5.24	825	5.69
			101				109	

Mixture A B2(2) Batch No.	180 Days Age Compressive Mixture A psi	MPa	Mixture B2(2) psi	MPa	365 Days Age Compressive Mixture A psi	MPa	Mixture B2(2) psi	MPa

Table 5

Results of Individual Tests of Setting Time, Relative Durability (DFE), Length Change, Air Void Spacing Factor ($\bar{L}$), and Averages

Mixture	Batch No.	Time of Setting: Initial hr	Initial min	Final hr	Final min	Specified	Relative DFE at 300 Cycles	Length-Change Shrinkage, in.
A	1	4	30	7	28		71 66	0.018
	2	4	20	7	5		77 78	0.014
	3	4	47	8	4		83 79	0.011
Average		4	36	7	32		76	0.014
B	1(a)*	4	40	7	48		28 32	0.016
	2	4	53	8	19		18 17	0.012
	3	5	5	8	47		7 11	0.007
Average		4	53	8	18		19	0.012
Deviation from control			+17		+46	Not more than 1 hr earlier nor 1-1/2 hr later		
A	4(b)*	5	0	7	10		84 84	0.015
	5	5	15	7	15		86 83	0.015
	6	6	0	7	50		89 86	0.016
Average		5	25	7	25		85	0.015
C	1	6	30	8	15		38 37	0.017
	2(c)*	6	20	7	55		55 55	0.013
	3	6	35	8	5		47 47	0.012
Average		6	25	8	5		47	0.014
Deviation from control		+1	0		+40	Not more than 1 hr earlier nor 1-1/2 hr later		
A	7	4	47	8	4		No test	No test
D	1	8	55	11	5		No test	No test
Deviation from control		+4	8	+3	1	Not more than 1 hr earlier nor 1-1/2 hr later		
A	8	5	0	7	50		76 77	No test
Average							76	
E	1(d)*	6	5	8	50		14 12	No test
Average							13	
Deviation from control		+1	5	+1	0	Not more than 1 hr earlier nor 1-1/2 hr later		
A	9	5	10	7	20		83 79	No test
Average							81	
C1	1(e)*	6	0	8	5		27 24	No test
Average							26	
Deviation from control			+50		+45	Not more than 1 hr earlier nor 1-1/2 hr later		

(Continued)

* (a) $\bar{L}$ = 0.011 in.
(b) $\bar{L}$ = 0.003 in.
(c) $\bar{L}$ = 0.008 in.
(d) $\bar{L}$ = 0.012 in.
(e) $\bar{L}$ = 0.009 in.

Table 5 (Concluded)

Mixture	Batch No.	Time of Setting: Initial hr	Initial min	Final hr	Final min	Specified	Relative DFE at 300 Cycles	Length-Change Shrinkage, in.
A	10	4	55	6	40		82 78	0.010
	11	5	20	7	20		81 81	0.010
Average		5	10	7	0		80	0.010
B1	1(f)*	4	45	6	40		77 77	0.007
	2	4	50	6	50		38 43	0.010
Average		4	50	6	45		59	0.008
Deviation from control			-20		-15	Not more than 1 hr earlier nor 1-1/2 hr later		
A	12	5	40	7	35		76 74	0.010
Average							75	0.010
E1	1	5	10	7	5		34 62	0.006
Average							48	0.006
Deviation from control			-30		-30	Not more than 1 hr earlier nor 1-1/2 hr later		
A	12	5	40	7	35		76 74	0.010
Average							75	0.010
C2	1	5	25	7	30		54 58	0.005
Average							56	0.005
Deviation from control			-15		-5	Not more than 1 hr earlier nor 1-1/2 hr later		
A	13	5	20	7	20		81 81	0.010
Average							81	0.010
B2	1	5	35	7	35		47 56	0.014
Average							52	0.014
Deviation from control			+15		+15	Not more than 1 hr earlier nor 1-1/2 hr later		
A	13	5	20	7	20		81 81	0.010
Average							81	0.010
B2(2)	1	5	0	6	45		62 57	0.001
Average							60	0.001
Deviation from control			-20		-35	Not more than 1 hr earlier nor 1-1/2 hr later		

* (f) $\overline{L}$ = 0.004 in.

Table 6

Average Values of Test Data and Specified Limits of CRD-C 87-72

Test	Mixture A B Batch No. (1,2,3) (1,2,3)	Mixture A C Batch No. (4,5,6) (1,2,3)	Mixture A D Batch No. (7) (1)	Mixture A E Batch No. (8) (1)	Mixture A C1 Batch No. (9) (1)	Specified
Water content, % of control	75.0	82.0	92.0	77.8	83.8	95 max
Initial setting time: Deviation from control	+17 min	+1 hr 0 min	+4 hr 8 min	+1 hr 5 min	+50 min	<+1 hr <-1-1/2 hr
Final setting time: Deviation from control	+46 min	+40 min	+3hr 1 min	+1 hr 0 min	+45 min	<+1 hr <-1-1/2 hr
3 days compressive strength: Percent of control	198	193	121	174	172	110 min
3 days flexural strength: Percent of control	135	151	129	126	143	100 min
7 days compressive strength: Percent of control	174	170	119	142	144	110 min
7 days flexural strength: Percent of control	119	138	112	127	149	100 min
28 days compressive strength: Percent of control	137	155	110	132	135	110 min
28 days flexural strength: Percent of control	121	120	95	118	118	100 min
180 days compressive strength: Percent of control	124	155	--	125	136	100 min
365 days compressive strength: Percent of control	141	153	--			100 min
Relative durability factor: Percent of control	25	55	--	17	32	80 min
Length change: Shrinkage percent control	86	93	--	--	--	135 max

Test	Mixture A B1 Batch No. (10,11) (1,2)	Mixture A E1 Batch No. (12) (1)	Mixture A C2 Batch No. (12) (1)	Mixture A B2 Batch No. (13) (1)	Mixture A B2(2) Batch No. (13) (1)	Specified
Water content, % of control	87.4	87.4	87.4	87.4	87.4	95 max
Initial setting time: Deviation from control	-20 min	-30 min	-15 min	+15 min	-20 min	<+1 hr <-1-1/2 hr
Final setting time: Deviation from control	-15 min	-30 min	-5 min	+15 min	-35 min	<+1 hr <-1-1/2 hr
3 days compressive strength: Percent of control	138	135	156	143	189	110 min
3 days flexural strength: Percent of control	122	122	130	129	145	100 min
7 days compressive strength: Percent of control	132	134	146	141	153	110 min
7 days flexural strength: Percent of control	120	122	129	111	144	100 min
28 days compressive strength: Percent of control	109	121	134	112	101	110 min
28 days flexural strength: Percent of control	95	114	112	87	109	100 min
180 days compressive strength: Percent of control						100 min
365 days compressive strength: Percent of control						100 min
Relative durability factor: Percent of control	74	64	75	64	74	80 min
Length change: Shrinkage percent control	80	60	50	140	10	135 max

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